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LXIX. *A Letter from Mr. J. Smeaton to Mr. John Ellicott, F.R.S. concerning some Improvements made by himself in the Air-Pump.*

S I R,

Read April 16, 1752. **I** HAVE been informed by some of my friends, that my endeavours towards completing the air-pump, have been mentioned with approbation, in papers that Mr. Short and Mr. Watſon have lately communicated to the Royal Society. I underſtand likewise, that the latter of thoſe gentlemen has, in a very obliging manner, expreſſed an inclination, that I ſhould lay before them a particular account of my improvements therein.

I ſhall always eſteem it a ſingular honour to be thought capable of producing any thing worthy the attention of the Royal Society ; and to be my duty and intereſt ſo to do, upon the leaſt intimation of that kind.

Your ſuperior ſkill in mechanics, together with the aſſiſtance you have given me in making trial of my pump, againſt three very good ones of the common conſtruction, as well as the frequent marks of friendſhip you have ſhewn me on all occaſions, encourage me to trouble you with communicating the following to that Society, of which you are a member, and who, of all others, are the moſt proper judges..

I ſhall

I shall not take up time with a particular recital of the alterations I have made, for near four years past, in order to remove some obstacles, which I imagined hindred the effects, that the theory I set out upon seemed to promise. It will be sufficient, that I give an account of what has appeared to answer best, after a great number of different trials; which, tho' short of what I at first expected, yet as this pump performs much better than the common ones, my labour may not be thought wholly useless; and the respect, which I have to the Society, would still have prevented me from troubling you or them about it at this time, could I have thought of any alteration, that promised materially to improve it.

The principal causes of imperfection in the common pumps arise, first, from the difficulty in opening the valves at the bottom of the barrels; and, 2dly, from the piston's not fitting exactly, when put close down to the bottom; which leaves a lodgement for air, that is not got out of the barrel, and proves of bad effect, as I shall shew in the course of this paper.

In regard to the first of these causes; the valves of air-pumps are commonly made of a bit of thin bladder, stretch'd over a hole generally much less than one tenth of an inch diameter; and to prevent the air from repassing between the bladder and the plate, upon which it is spread, the valve must always be kept moist with oil or water.

It is well known, that at each stroke of the pump the air is more and more rarefied, in a certain progression, which would be such, that an equal proportion

proportion of the remainder would be taken away, was it not affected by the impediments I have mentioned: so that, when the spring of the air in the receiver becomes so weak, as not to be able to overcome the cohesion of the bladder to the plate, occasioned by the fluid between them, the weight of the bladder, and the resistance that it makes by being stretch'd, the rarefaction cannot be carried farther, tho' the pump should still continue to be worked.

It is evident, that the larger the * hole is, over which the bladder is laid, a proportionably greater force is exerted upon it by the included air, in order to lift it up; but the aperture of the hole cannot be made very large, because the pressure of the incumbent air would either burst the valve, or so far force it down into the cavity, as to prevent its lying flat and close upon the plate, which is absolutely necessary.

To avoid these inconveniences as much as possible, instead of one hole, I have made use of seven, all of equal size and shape; one being in the centre, and the other six round it: so that the valve is supported at proper distances, by a kind of grating, made by the solid parts between these holes: And to render the points of contact, between the bladder and grating, as few as possible, the holes are made hexagonal, and the partitions filed almost to an edge. As the whole pressure of the atmosphere can never be exerted upon
this

* If we examine the force, that air rarefied 140 times can exert in a common valve through a hole of one tenth of an inch diameter, we shall find it not to exceed 6 grains at a medium.

this valve, in the construction made use of in this pump; and as the bladder is fastened in four places instead of two, I have made the breadth of the hexagons three tenths of an inch; so that the surface of each of them is more than nine times greater than common. But as the circumference of each hole is more than three times greater than common, and as the force, that holds down the valve, arising from cohesion, is, in the first moment of the air's exerting its force, proportionable to the circumference of the hole; the valve over any of these holes will be raised with three times more ease than common. But as the raising of the valve over the center-hole is assisted on all sides by those placed round it; and as they all together contribute as much to raise the bladder over the center-hole, as the air immediately acting under it; upon this account the valve will be raised with double the ease, that we have before supposed, or with a sixth part of the force commonly necessary.

It is not material to consider the force of the cohesion, after the first instant: For, after the bladder begins to rise, it exposes a greater surface to the air underneath, which makes it move more easily. I have not brought into this account the force, that keeps down the valve, that arises from the weight of the bladder, and the resistance from its being stretch'd; for I look upon these as small, in comparison of the other.

I was not however contented with this construction of the valves, till I had tried what effect would be produced, when they were opened by the motion of the winch, independent of the spring of the air:

And tho' the contrivance I made use of seemed to me less liable to objection than any thing I was acquainted with, that had been designed for that purpose; yet I did not find it to answer the end better than what I have already described; and therefore laid it aside, as it render'd the machinery much more complex, and troublesome to execute.

But supposing all those difficulties to be absolutely overcome, the other defect, that I mentioned in the common construction, would hinder the rarefaction from being carried on beyond a certain degree. For, as the piston cannot be made to fit so close to the bottom of the barrel, as totally to exclude all the air; as the piston rises, this air will expand itself; but still pressing upon the valve, according to its density, hinders the air within the receiver from coming out: Hence, were this vacancy to equal the 150th part of the capacity of the whole barrel, no air could ever pass out of the receiver, when expanded 150 times, tho' the piston was constantly drawn to the top; because the air in the receiver would be *in æquilibrio* with that in the barrel, when in its most expanded state. This I have endeavoured to overcome, by shutting up the top of the barrel with a plate, having in the middle a collar of leathers, through which the cylindrical rod works, that carries the piston. By this means, the external air is prevented from pressing upon the piston; but that the air, that passes thro' the valve of the piston from below, may be discharged out of the barrel, there is also a valve applied to the plate at the top, that opens upwards. The consequence of this construction is, that when the piston is put down to the bottom of the cylinder, the air in the lodgment under the piston will evacuate

itself so much the more, as the valve of the piston opens more easily, when pressed by the rarefied air above it, than when pressed by the whole weight of the atmosphere. Hence, as the piston may be made to fit as nearly to the top of the cylinder, as it can to the bottom, the air may be rarefied as much above the piston, as it could before have been in the receiver. It follows therefore, that the air may now be rarefied in the receiver, in duplicate proportion of what it could be upon the common principle; every thing else being supposed perfect.

Another advantage of this construction is, that tho' the pump is composed of a single barrel*, yet the pressure of the outward air being taken off by the upper plate, the piston is worked with more ease § than the common pumps with two barrels: And not only so, but when a considerable degree of rarefaction is desired, it will do it quicker; for the terms of the series expressing the quantity of air taken away at each stroke do not diminish so fast, as the series answering to the common one.

I have found the gages, that have been hitherto made use of, for measuring the expansion of the air, very unfit to determine in an experiment of so much nicety.

* It is obvious that these improvements will equally obtain, whether the pump is constructed with a single or a double barrel.

§ Because, tho' the pressure of a column of air, equal to the diameter of the piston-rod, still presses upon it, yet, as there is only the friction of one piston, and that not loaded with the weight of the atmosphere; the friction of the leather against the side of the barrel, and that of the rack and wheel, is much less: so that, notwithstanding the addition of friction in the collar of leathers, that of the whole will be less.

nicety. I have therefore contrived one of a different sort, which measures the expansion with certainty, to much less than the 1000th part of the whole. It consists of a bulb of glass something in the shape of a pear, and sufficient to hold about half a pound of quicksilver. It is open at one end, and at the other is a tube hermetically closed at top. By the help of a nice pair of scales, I found what proportion of weight a column of mercury, of a certain length, contained in the tube, bore to that, which filled the whole vessel. By these means I was enabled to mark divisions upon the tube, answering to a 1000th part of the whole capacity, which being of about one tenth of an inch each, may, by estimation, be easily subdivided into smaller parts. This gage, during the exhausting of the receiver, is suspended therein by a slip-wire. When the pump is worked as much as shall be thought necessary, the gage is pushed down, till the open end is immersed in a cistern of quicksilver placed underneath: The air being then let in, the quicksilver will be driven into the gage*; till the air remaining in it becomes of the same density with the external; and as the air always takes the highest place, the tube being uppermost, the expansion will be determined by the number of divisions occupied by the air at the top.

The degree, to which I have been able to rarefy the air in experiment, has generally been about 1000 times,

* The bulb of the gage may be emptied of its quicksilver, without taking that out of the tube; and the tube being held horizontal, the column of mercury in it will have power to contract or expand the air at the top.

times, when the pump is put clean together : But the moisture, that adheres to the inside of the barrel, as well as other internal parts, upon letting in the air, is in the same succeeding trials worked together with the oil, which soon renders it so clammy, as to obstruct the action of the pump upon a fluid so subtil as the air is, when so much expanded ; but in this case it seldom fails to act upon the air in the receiver, till it is expanded 500 times : And this I have found it to do, after being frequently used for several months, without cleaning. I have also generally found it to perform best, the first trial at each time of using ; tho' nothing had been at it from the time preceding ; which, after a great many trials made with this view, I also attribute to the vapours of the air mixing with the oil. An experiment, where the air was expanded 1000 times, was tried about two years since in your presence ; at which were present also Dr. Knight and Mr. Canton ; and I lately did the same thing with Mr. Watson. The pump, which I intend myself the honour of shewing the Society, is the same, that I just now mention'd, and the second that I made, with a view to improve upon this principle.

The degree of rarefaction, produced by the best of the three pumps, that you procured the trial of, and which you esteemed good in their kind, and in complete order, never exceeded 140 times, when tried by the gage above described.

I have also endeavoured to render the pneumatic apparatus more simple and commodious, by making this air-pump act as a condensing engine at pleasure, by singly turning a cock. This not only enables us
to

to try any experiments under different circumstances of pressure, without changing the apparatus, but renders the pump an universal engine, for shewing any effect, that arises from an alteration in the density or spring of the air. Thus, with a little addition of apparatus, it shews the experiments of the air-fountain, wind-gun, &c.

This is done in the following manner: The air above the piston being forcibly driven out of the barrel at each stroke, and having no-where to escape, but by the valve at the top; if this valve be connected with the receiver, by means of a pipe, and at the same time the valve at the bottom, instead of communicating with the receiver, be made to communicate with the external air, the pump will then perform as a condenser.

The mechanism is thus ordered. There is a cock with three pipes placed round it, at equal distances. The key is so pierced, that any two may be made to communicate, while the other is left open to the external air. One of these pipes goes to the valve at the bottom of the barrel; another goes to the valve at the top, and a third goes to the receiver. Thus, when the pipe from the receiver, and that from the bottom of the barrel, are united, the pump exhausts: But turn the cock round, till the pipe from the receiver, and that from the top of the barrel, communicate, and it then condenses. The third pipe, in one case, discharges the air, taken from the receiver, into the barrel; and in the other, lets it into the
barrel,

barrel, that it may be forced into the receiver. I
am,

S I R,

Furnival's-Inn-court,
April 16, 1752.

Your most humble servant,

J. Smeaton.

P. S. I have also added some draughts, and letters of reference, in order to explain myself more fully.

Figure I.

Is a perspective view of the principal parts of the pump together.

A is the barrel.

B the cistern, in which are included the cock, with several joints. These are cover'd with water to keep them air-tight. A little cock to let the water out of the cistern, is marked 6.

Ccc is the triangular handle of the key of the cock: which, by the marks on its arms, shews how it it must be turned, that the pump may produce the effect desired.

DH is the pipe of communication between the cock and the receiver.

E is the pipe, that communicates between the cock and the valve, on the upper plate of the barrel.

F is the upper plate of the pump, which contains the collar of leathers *d*, and *V* the valve, which is covered by the piece *f*.

GI

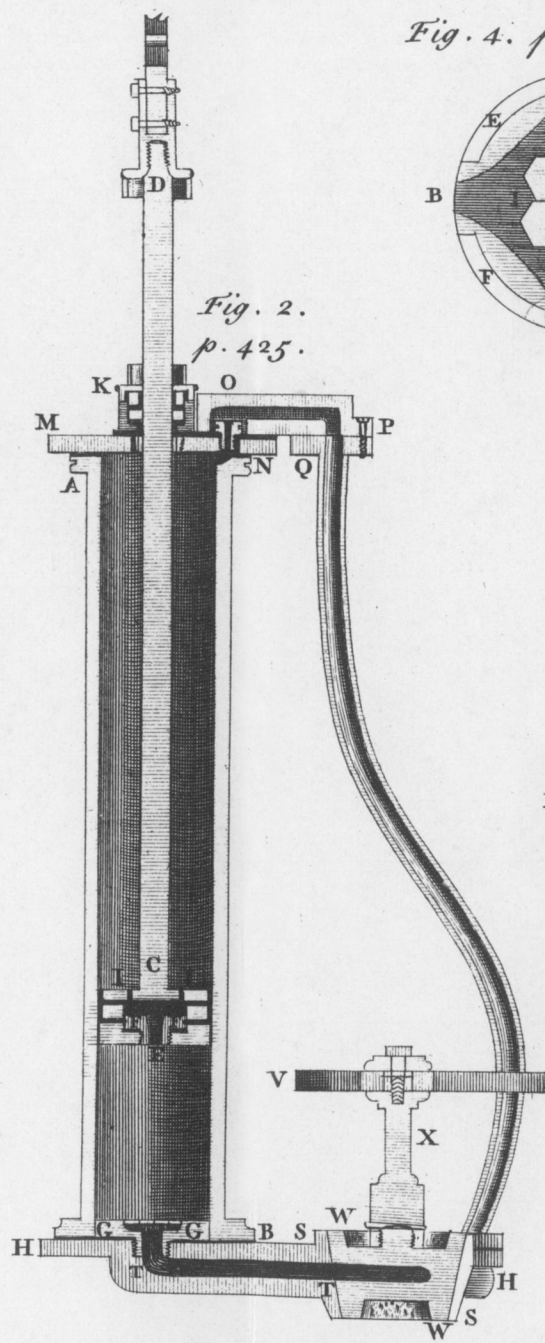
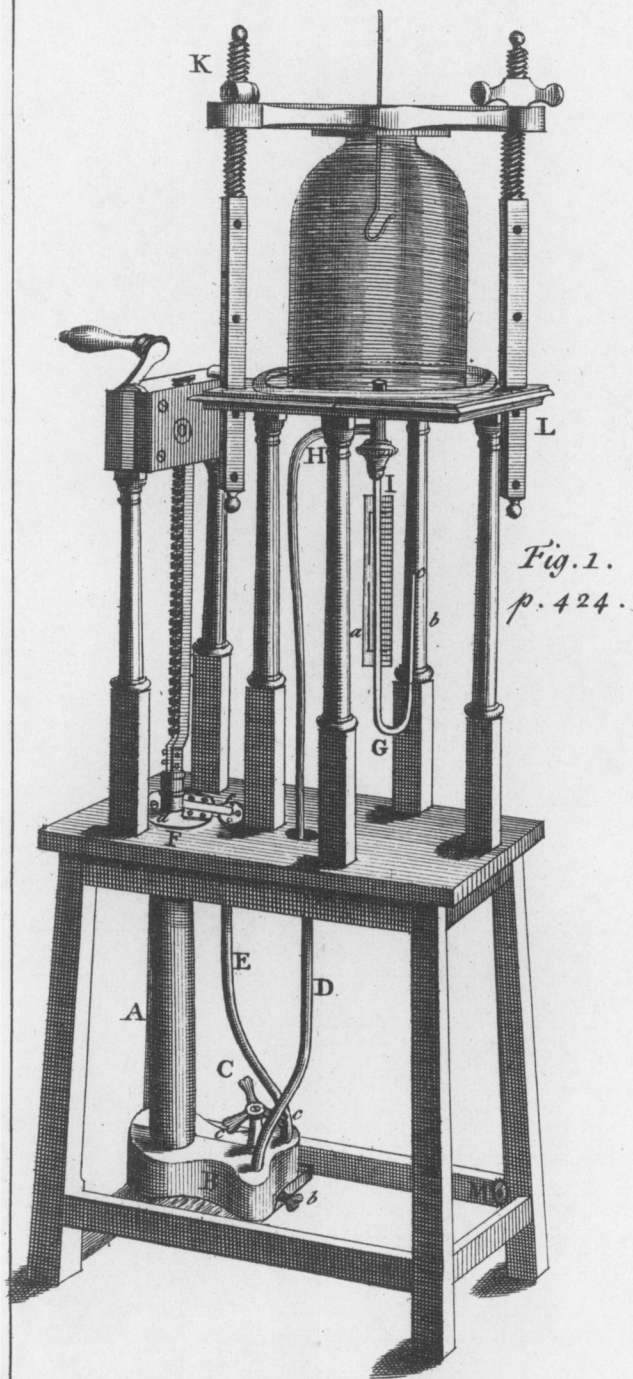


Fig. 4.



Fig. 4. p. 427.

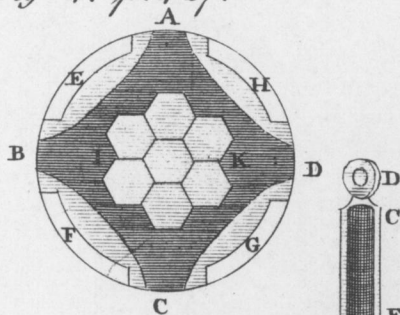


Fig. 2.

p. 425.

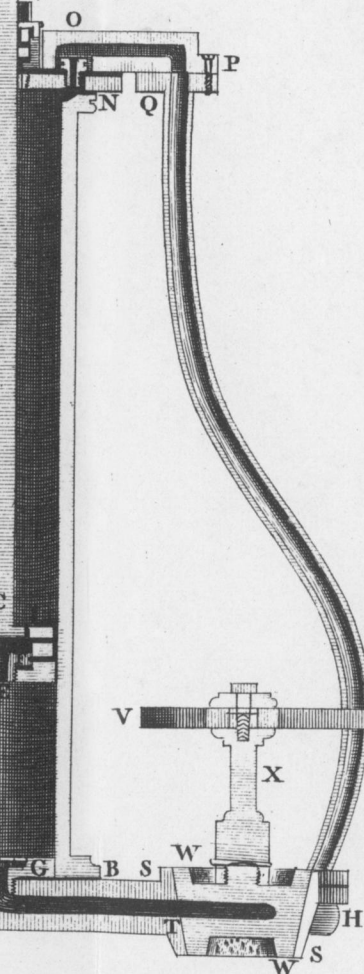


Fig. 5.
p. 428.

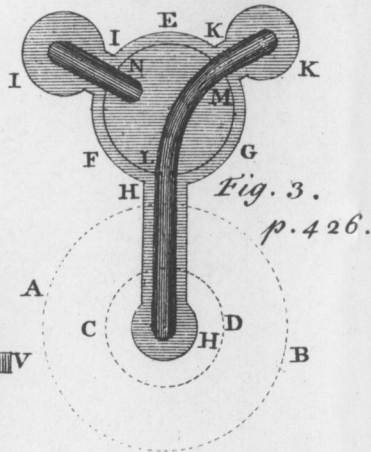
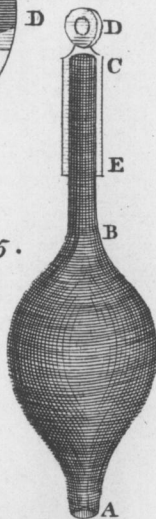
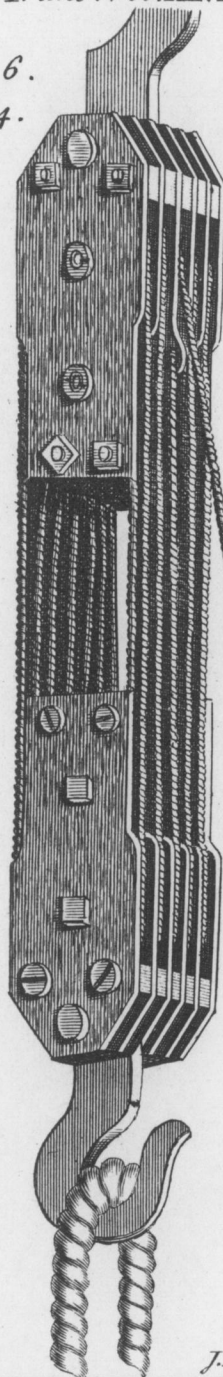


Fig. 3.

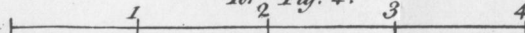
p. 426.

Fig. 6.
p. 494.



A Scale of Inches.

For Fig. 4.



J. Mynde Sc.

GI is the siphon-gage; which screws on and off, and is adapted to common purposes. It consists of a glass tube hermetically sealed at *c*, and furnished with quicksilver in each leg; which, before the pump begins to work, lies level in the line *ab*; the space *bc* being filled with air of the common density. When the pump exhausts, the air in *bc* expands, and the quicksilver in the opposite leg rises, till it becomes a counter-balance to it. Its rise is shewn upon the scale *Ie*, by which the expansion of the air in the receiver may be nearly judged of. When the pump condenses, the quicksilver rises in the other leg, and the degree may be nearly judged of by the contraction of the air in *bc*: marks being placed at $\frac{1}{2}$ and $\frac{1}{3}$ of the length of *bc* from *c*; which shews when the receiver contains double or treble its common quantity.

KL is a screw-frame to hold down the receiver, in condensing experiments, which takes off at pleasure; and is sufficient to hold down a receiver, the diameter of whose base is 7 inches, when charged with a treble atmosphere: in which case it acts with a force of about 1200 pounds against the screw-frame.

M is a screw, that fastens a bolt, which slides up and down in that leg, by means whereof the machine is made to stand fast on uneven ground.

Fig. II.

Is a perpendicular section of the barrel and cock, &c. where

AB represents the barrel.

H h h

CD

CD the rod of the piston, which passes through
MN the plate, which closes the top of the barrel.
K is the collar of leathers, through which the piston-rod passes. When the piston is at the bottom of the cylinder, the upper part of *K* is covered by the cap at *D*, to keep out dust, &c.
L is the valve on the upper plate, which is covered by the piece
OP, which is connected with the pipe
QR, which makes the communication between the valve and cock.
CE is the piston; and
EFF is the piston-valve.
II are two little holes to let the air pass from the piston-valve into the upper part of the barrel.
GGK is the principal valve at the bottom of the cylinder.
HH is a piece of metal, into which the valve *GGK* is screw'd, and closes the bottom of the cylinder; out of which also is composed
SS the cock, and
KTT the duct from the cock to the bottom of the barrel.
WW is the key of the cock,
X the stem; and
VV the handle.

Fig. III.

Is an horizontal section of the cock, through the middle of the duct *TT*.

AB represents the bigness of the circular plate, that closes the bottom of the barrel.

CD

CD represents the bigness of the inside of the barrel.
EFG is the body of the cock; the outward shell
 being pierced with 3 holes at equal distances, and
 corresponding to the three ducts *HH*, *II*, *KK*,
 whereof

HH is the duct, that goes to the bottom of the barrel.
II, the duct, that communicates with the top of the
 barrel; and

KK is the duct, that passes from the cock to the re-
 ceiver.

LMN is the key, or solid part of the cock, move-
 able round in the shell *EFG*. When the canal
LM answers to the ducts *HH* and *KK*, the pump
 exhausts, and the air is discharged by the perfora-
 tion *N*. But the key *LMN* being turned till the
 canal *LM* answers to *II* and *KK*, the perforation
N will then answer to *HH*; and in this case the
 pump condenses. Lastly, when *N* answers to *KK*,
 the air is then let in or discharged from the receiver,
 as the circumstance requires.

Fig. IV.

Is the plan of the principal valve.

ABCD represents the bladder fasten'd in 4 places,
 and stretch'd over the 7 holes *IK*, formed into an
 hexagonal grating; which I shall call the honey-
 comb.

EFGH shews where the metal is a little protuberant,
 to hinder the piston from striking against the
 bladder.

Fig. V.

Represents the new gage; which I call the pear-gage. It is open at *A*; *BC* is the graduated tube, which is hermetically closed at *C*, and is suspended by the piece of brass *DE*, that is hollowed into a cylinder, and clasps the tube.

LXX. *An Account of Aphyllon and Dentaria heptaphyllos of Clusius, omitted by Mr. Ray : by Mr. William Watson, F. R. S.*

Read April 16, 1752. **M**R. Watson presented to the Society some specimens of two plants, now in flower, which he said were not frequently found in England. One of them was the *Anblatum* of Cordus, or *Aphyllon* of John Bauhin. This plant is denominated *Squamaria* by Rivinus, and *Dentaria codylia* by Tabernamontanus. Linnæus, in the *Flora Suecica*, calls it *Lathræa caule simplicissimo, corollis nutantibus, labio inferiore trifido*. Mr. Ray, in his *Synopsis plantarum Angliæ*, takes notice of its being found near Darking in Surrey, but the plant now presented was collected near Harefield in Middlesex.

The other plant offered was the *Dentaria heptaphyllos baccifera* of Caspar Bauhin, or *Dentaria tertia baccifera* of Clusius. This plant is treated of by Linnæus, in the *Hortus Cliffortianus*, and by Van Royen, in the *Floræ Leydensis prodromus*, under the appellation of *Dentaria foliis inferioribus palmatis, summis simplicibus*.

This